

**PCT**WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau

## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<b>(51) International Patent Classification <sup>6</sup>:</b> <b>H02K 3/40, H01B 9/02</b>	<b>A1</b>	<b>(11) International Publication Number:</b> <b>WO 99/29022</b> <b>(43) International Publication Date:</b> 10 June 1999 (10.06.99)
<b>(21) International Application Number:</b> PCT/EP98/07731 <b>(22) International Filing Date:</b> 30 November 1998 (30.11.98) <b>(30) Priority Data:</b> 9725329.8 28 November 1997 (28.11.97) GB <b>(71) Applicant (for all designated States except US):</b> ASEA BROWN BOVERI AB [SE/SE]; S-721 78 Västerås (SE). <b>(72) Inventors; and</b> <b>(75) Inventors/Applicants (for US only):</b> CARSTENSEN, Peter [DK/SE]; Sjövägen 62, S-141 42 Huddinge (SE). KY- LANDER, Gunnar [SE/SE]; Stentorpsgatan 16A, S-723 43 Västerås (SE). <b>(74) Agent:</b> NEWBY, Martin, John; J.Y. & G.W. Johnson, Kings- bourne House, 229-231 High Holborn, London WC1V 7DP (GB).		<b>(81) Designated States:</b> AL, AM, AT, AT (Utility model), AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, EE (Utility model), ES, FI, FI (Utility model), GB, GD, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report.</i> <i>Before the expiration of the time limit for amending the</i> <i>claims and to be republished in the event of the receipt of</i> <i>amendments.</i>
<b>(54) Title:</b> INSULATED CONDUCTOR FOR HIGH-VOLTAGE MACHINE WINDINGS  <b>(57) Abstract</b> <p>An insulated conductor (10) for high-voltage windings in electric machines comprises a number of strands (12), a first semi-conductive layer (14) surrounding the strands (12), a first insulating layer (16) surrounding the first semi-conductive layer (14), a second semi-conductive layer (18) surrounding the first insulating layer (16), and a third semi-conductive layer (19) surrounding the second semi-conductive layer (18). The second semi-conductive layer (18) is earthed at at least two different points along the insulated conductor (30). Electric conductivity in the third semi-conductive layer (19) is broken (20) between each pair of earthed points.</p> <div data-bbox="662 1163 1318 1612" data-label="Image"> </div>		

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

## INSULATED CONDUCTOR FOR HIGH-VOLTAGE MACHINE WINDINGS

### TECHNICAL FIELD

The present invention relates in a first aspect to an insulated conductor for high-voltage windings in rotating  
5 electric machines and also possibly transformers.

A second aspect of the present invention relates to a rotating electric machine comprising an insulated conductor of the type described above.

A particularly useful application of the invention is in a  
10 generator in a power station for generating electric power.

The invention is applicable in rotating electric machines such as synchronous machines. The invention is also applicable in other electric machines such as dual-fed machines, and applications in asynchronous static current  
15 cascades, outer pole machines and synchronous flow machines, provided their windings consist of insulated electric conductors of the invention, and preferably at high voltages. "High voltages" here refers to electric voltages exceeding 10 kV, in particular in excess of 36 kV, and  
20 preferably more than 72.5 kV up to very high voltages such as 400 kV to 800 kV or higher.

### BACKGROUND ART:

In order to be able to explain and describe the machine, a brief description of a rotating electric machine will first  
25 be given, exemplified on the basis of a synchronous machine. The first part of the description substantially relates to the magnetic circuit of such a machine and how it is constructed according to classical technique. Since the magnetic circuit referred to in most cases is located in the  
30 stator, the magnetic circuit below will normally be

- 2 -

described as a stator with a laminated core, the winding of which will be referred to as a stator winding, and the slots in the laminated core for the winding will be referred to as stator slots or simply slots.

5 The stator winding is located in slots in the sheet iron core, the slots normally having a rectangular or trapezoidal cross section. Each winding phase comprises a number of series-connected coil groups and each coil group comprises a number of series-connected coils. The different parts of  
10 the coil are designated coil side for the part which is placed in the stator and winding end for that part which is located outside the stator. A coil comprises one or more conductors brought together in height and/or width.

Between each conductor there is a thin insulation, for  
15 example epoxy/glass fibre.

The coil is insulated from the slot with a coil insulation, that is, an insulation intended to withstand the rated voltage of the machine to earth. As insulating material, various plastic, varnish and glass fibre materials may be  
20 used. Usually, so-called mica tape is used, which is a mixture of mica and hard plastic, especially produced to provide resistance to partial discharges, which can rapidly break down the insulation. The insulation is applied to the coil by winding the mica tape around the coil in several  
25 layers. The insulation is impregnated, and then the coil side is painted with a graphite-based paint to improve the contact with the surrounding stator which is connected to earth potential.

The conductor area of the windings is determined by the  
30 current intensity in question and by the cooling method used. The conductor and the coil are usually formed with a rectangular shape to maximize the amount of conductor material in the slot. A typical coil is formed of so-called Roebel bars, in which certain of the bars may be made hollow

- 3 -

for a coolant. A Roebel bar comprises a plurality of rectangular, parallel-connected copper conductors which are transposed 360 degrees along the slot. Ringland bars with transpositions of 540 degrees and other transpositions also occur. The transposition is made to avoid the occurrence of circulating currents which are generated in a cross section of the conductor material, as viewed from the magnetic field.

For mechanical and electrical reasons, a machine cannot be made in just any size. The machine power is determined substantially by three factors:

- The conductor area of the windings. At normal operating temperature, copper, for example, has a maximum value of 3-3.5 A/mm<sup>2</sup>.
- The maximum flux density (magnetic flux) in the stator and rotor material.
- The maximum electric field strength in the insulating material, the so-called dielectric strength.

Polyphase ac windings are designed either as single-layer or two-layer windings. In the case of single-layer windings, there is only one coil side per slot, and in the case of two-layer windings there are two coil sides per slot. Two-layer windings are usually designed as diamond windings, whereas the single-layer windings which are relevant in this connection may be designed as a diamond winding or as a concentric winding. In the case of a diamond winding, only one coil span (or possibly two coil spans) occurs, whereas flat windings are designed as concentric windings, that is, with a greatly varying coil span. By coil span is meant the circumferential distance between two coil sides belonging to the same coil, either in relation to the relevant pole pitch or in the number of intermediate slot pitches. Usually, different variants of chording are used, for example short-pitching pitch, to give the winding the desired properties.

The type of winding substantially determines how the coils

- 4 -

in the slots, that is, the coil sides, are connected together outside the stator, that is, at the winding ends.

Outside the stacked sheets of the stator, the coil is not provided with a painted semiconducting earth-potential layer. The end winding end is normally provided with an E-field control in the form of so-called corona protection varnish intended to convert a radial field into an axial field, which means that the insulation on the end windings ends occurs at a high potential relative to earth. This sometimes gives rise to corona in the winding-end region, which may be destructive. The so-called field-controlling points at the winding ends entail problems for a rotating electric machine.

Normally, all large machines are designed with a two-layer winding and equally large coils. Each coil is placed with one side in one of the layers and the other side in the other layer. This means that all the coils cross each other at the winding ends. If more than two layers are used, these crossings render the winding work difficult and deteriorate the winding ends.

It is generally known that the connection of a synchronous machine/generator to a power network must be made via a  $\Delta$ /YD-connected so-called step-up transformer, since the voltage of the power network normally lies at a higher level than the voltage of the rotating electric machine. Together with the synchronous machine, this transformer thus constitutes integrated parts of a plant. The transformer constitutes an extra cost and also has the disadvantage the advantage that the total efficiency of the system is lowered. If it were possible to manufacture machines for considerably higher voltages, the step-up transformer could thus be omitted.

During the last few decades, there have been increasing requirements for rotating electric machines with higher

- 5 -

rated voltages than for what has previously been possible to design. The maximum voltage level which, according to the state of the art, has been possible to achieve for synchronous machines with a good yield in the coil  
5 production is around 25-30 kV.

Certain attempts to a new approach as regards the design of synchronous machines are described, inter alia, in an article entitled "Water-and-oil-cooled Turbogenerator TVM-300" in J. Elektrotechnika, No. 1, 1970, pp. 6-8, in US  
10 4,429,244 "Stator of Generator" and in Soviet Union Patent No. 955369.

The water- and oil-cooled synchronous machine described in J. Elektrotechnika is intended for voltages up to 20 kV. The article describes a new insulation system consisting of  
15 oil/paper insulation, which makes it possible to immerse the stator completely in oil. The oil can then be used as a coolant and an insulator at the same time. To prevent oil in the stator from leaking out towards the rotor, a dielectric oil-separating ring is provided at the internal surface of  
20 the core. The stator winding is made from conductors with an oval hollow shape provided with oil and paper insulation. The coil sides with their insulation are secured to the slots made with rectangular cross section by means of wedges. As coolant, oil is used both in the hollow  
25 conductors and in holes in the stator walls. Such cooling systems, however, entail a large number of connections of both oil and electricity at the coil ends. The thick insulation also entails an increased radius of curvature of the conductors, which in turn results in an increased size  
30 of the winding overhang.

The above-mentioned US patent relates to the stator part of a synchronous machine which comprises a magnetic core of laminated sheet with trapezoidal slots for the stator winding. The slots are tapered since the need for insulation  
35 of the stator winding is less towards the interior of the

- 6 -

rotor where that part of the winding which is located nearest the neutral point is located. In addition, the stator part comprises a dielectric oil-separating cylinder nearest the inner surface of the core. This part may  
5 increase the magnetization requirement relative to a machine without this ring. The stator winding is made of oil-immersed cables with the same diameter for each coil layer. The layers are separated from each other by means of spacers in the slots and secured by wedges. What is special for the  
10 winding is that it comprises two so-called half-windings connected in series. One of the two half-windings is located, centered, inside an insulating sleeve. The conductors of the stator winding are cooled by surrounding oil. Disadvantages with such a large quantity of oil in the  
15 system are the risk of leakage and the considerable amount of cleaning work which may result from a fault condition. Those parts of the insulating sleeve which are located outside the slots have a cylindrical part and a conical termination reinforced with current-carrying layers, the  
20 purpose of which is to control the electric field strength in the region where the cable enters the end winding.

From SU 955369 it is clear, in another attempt to raise the rated voltage of the synchronous machine, that the oil-cooled stator winding comprises a conventional high-voltage  
25 cable with the same dimension for all the layers. The cable is placed in stator slots formed as circular, radially located openings corresponding to the cross-section area of the cable and the necessary space for fixing and for coolant. The different radially located layers of the  
30 winding are surrounded by and fixed in insulating tubes. Insulating spacers fix the tubes in the stator slot. Because of the oil cooling, an internal dielectric ring is also needed here for sealing the oil coolant off against the internal air gap. The disadvantages of oil in the system  
35 described above also apply to this design. The design also exhibits a very narrow radial waist between the different stator slots, which implies a large slot leakage flux which



- 7 -

significantly influences the magnetization requirement of the machine.

A report from Electric Power Research Institute, EPRI, EL-3391, from 1984 describes a review of machine concepts for achieving a higher voltage of a rotating electric machine with the purpose of being able to connect a machine to a power network without an intermediate transformer. Such a solution is judged by the investigation to provide good efficiency gains and great economic advantages. The main reason it was considered possible in 1984 to start developing generators for direct connection to power networks was that at the time a superconducting rotor had been produced. The large magnetization capacity of the superconducting field makes it possible to use an air gap winding with a sufficient insulation thickness to withstand the electrical stresses. By combining the most promising concept, according to the project, of designing a magnetic circuit with a winding, a so-called monolith cylinder armature, a concept where the winding comprises two cylinders of conductors concentrically enclosed in three cylindrical insulating casings and the whole structure being fixed to an iron core without teeth, it was judged that a rotating electric machine for high voltage could be directly connected to a power network. The solution meant that the main insulation had to be made sufficiently thick to cope with network-to-network and network-to-earth potentials. The insulation system which, after a review of all the technique known at the time, was judged to be necessary to manage an increase to a higher voltage was that which is normally used for power transformers and which consists of dielectric-fluid-impregnated cellulose press board. Obvious disadvantages with the proposed solution are that, in addition to requiring a superconducting rotor, it requires a very thick insulation which increases the size of the machine. The end windings must be insulated and cooled with oil or freons to control the large electric fields in the ends. The whole machine must be hermetically enclosed to

- 8 -

prevent the liquid dielectric from absorbing moisture from the atmosphere.

JP-A-8-195129 describes a high voltage cable, especially a long superhigh voltage CV cable, having two outer semiconductive layers, of which the internal layer has a higher resistivity than the external layer. However, because of the outer metallic screen of this cable, it would be totally unsuitable and dangerous for use in a rotating machine or transformer.

10 More generally, it is known that a high-voltage cable for transmission of electric energy is composed of conductors with solid extruded insulation with an inner and an outer semiconductor part. In the process of transmitting electric energy it was required that the insulation should be free  
15 from defects. During transmission of electric energy, the starting-point has long been that the insulation should be free from defects. When using high-voltage cables for transmission of electric energy, the aim was not been to maximize the current through the cable since space is no  
20 limitation for a transmission cable.

When manufacturing rotating electric machines according to the state of the art, the winding is manufactured with conductors and insulation systems in several steps, whereby the winding must be preformed prior to mounting on the  
25 magnetic circuit. Impregnation for preparing the insulation system is performed after mounting of the winding on the magnetic circuit.

To increase the power of a rotating electrical machine, it is known to increase the current in the AC coils. This has  
30 been achieved by optimizing the quantity of conducting material, that is, by close-packing of rectangular conductors in the rectangular rotor slots. The aim has been to handle the increase in temperature resulting from this by increasing the quantity of insulating material and using

- 9 -

more temperature-resistant and hence more expensive insulating materials. The high temperature and field load on the insulation has also caused problems with the life of the insulation. In the relatively thick-walled insulating layers 5 which are used for high-voltage equipment, for example impregnated layers of mica tape, partial discharges, PD, constitute a serious problem. When manufacturing these insulating layers, cavities, pores, and the like, will easily arise, in which internal corona discharges arise when 10 the insulation is subjected to high electric field strengths. These corona discharges gradually degrade the material and may lead to electric breakdown through the insulation.

**SUMMARY OF THE INVENTION:**

15 It is an object of the invention to be able to manufacture a rotating electric machine for high voltage without any complicated preforming of the winding and without having to impregnate the insulation system after mounting of the winding.

20 The present invention is based on the realization that, to be able to increase in the power of a rotating electrical machine in a technically and economically justifiable way, this must be achieved by ensuring that the insulation is not broken down by the phenomena described above. This can be 25 achieved by using, as insulation, layers made in such a way that the risk of cavities and pores is minimal, for example extruded layers of a suitable solid insulating material, such as thermoplastic resins, cross linked thermoplastic resins, rubber such as silicone rubber, etc. In addition, it 30 is important that the insulating layer comprises an inner layer, surrounding the conductor, with semiconducting properties and that the insulation is also provided with at least one additional outer layer, surrounding the insulation, with semiconducting properties. "Semiconducting" 35 refers in this context to a material which has a

- 10 -

considerably lower conductivity than an electric conductor but which does not have such a low conductivity that it is an insulator. By using only insulating layers which may be manufactured with a minimum of defects and, in addition, 5 providing the insulation with an inner and an outer semiconducting layer, it can be ensured that the thermal and electric loads are reduced. The insulating part with at least one adjoining semiconducting layer should have essentially the same coefficient of thermal expansion. At 10 temperature gradients, defects caused by different temperature expansion in the insulation and the surrounding layers should not arise. The electric load on the material decreases as a consequence of the fact that the semiconducting layers around the insulation will constitute 15 equipotential surfaces and that the electrical field in the insulating part will be distributed relatively evenly over the thickness of the insulation. The outer semiconducting layer may be connected to a chosen potential, for example earth potential. This means that, for such a cable, the 20 outer casing of the winding over its entire length may be kept at, for example, earth potential. The outer layer may also be cut off at suitable locations along the length of the conductor and each cut-off partial length may be directly connected to a chosen potential.

25 The present invention provides an insulated conductor for high-voltage windings in rotating electric machines as defined in claim 1 and also a rotating electric machine comprising such an insulated conductor. The high-voltage cable according to the present invention comprises one or 30 more strands surrounded by a first semi-conducting layer. This first semi-conducting layer is in turn surrounded by a first insulating layer, which is surrounded by second and third semi-conducting layers. The second semi-conducting layer is of higher resistivity than the third semi- 35 conducting layer, which is earthed at least two different points along the high-voltage cable. The part of the cable that lies in the stator slots should be electrically

- 11 -

insulated from the magnetic steel of the stator. Between each pair of earthed points along the high-voltage cable, the continuity of the electric contact is broken in the third semi-conducting layer. At each such break in the  
5 third semi-conductive layer a device may be arranged to reduce amplification of the electric field strength at said breaks.

Thanks to the high-voltage cable according to the invention no heat losses are caused by induced voltages in the outer  
10 semi-conducting layer. A high-voltage cable is obtained in which the risk of electric breakthrough has been minimized. In forming the break in third semi-conductive layer, any risk of cutting into the insulating layer is avoided, the second semi-conductive layer remaining substantially intact.

15 Further knowledge gained in connection with the present invention is that increased current load leads to problems with electric (E) field concentrations at the corners at a cross section of a coil and that this entails large local loads on the insulation there. Likewise, the magnetic (B)  
20 field in the teeth of the stator will be concentrated at the corners. This means that magnetic saturation arises locally and that the magnetic core is not utilized in full and that the wave form of the generated voltage/current will be distorted. In addition, eddy-current losses caused by induced  
25 eddy currents in the conductors, which arise because of the geometry of the conductors in relation to the B field, will entail additional disadvantages in increasing current densities. A further improvement of the invention is achieved by making the coils and the slots in which the coils are  
30 placed essentially circular instead of rectangular. By making the cross section of the coils circular, these will be surrounded by a constant B field without concentrations where magnetic saturation may arise. Also the E field in the coil will be distributed evenly over the cross section and  
35 local loads on the insulation are considerably reduced. In addition, it is easier to place circular coils in slots in

- 12 -

such a way that the number of coil sides per coil group may increase and an increase of the voltage may take place without the current in the conductors having to be increased. The reason for this is that the cooling of the  
5 conductors is facilitated by, on the one hand, a lower current density and hence lower temperature gradients across the insulation and, on the other hand, by the circular shape of the slots which entails a more uniform temperature distribution over a cross section. Additional improvements  
10 may also be achieved by composing the conductor from smaller parts, so-called strands. The strands may be insulated from each other and only a small number of strands may be left uninsulated and in contact with the inner semiconducting layer, to ensure that this is at the same potential as the  
15 conductor.

An advantage of using a rotating electric machine according to the invention is that the machine can be operated at overload for a considerably longer period of time than what is usual for such machines without being damaged. This is a  
20 consequence of the composition of the machine and the limited thermal load of the insulation. It is, for example, possible to load the machine with up to 100% overload for a period exceeding 15 minutes and up to two hours.

One embodiment according to the invention is that the  
25 magnetic circuit of the rotating electric machine comprises a winding of a threaded cable with one or more extruded insulated conductors with solid insulation with a semiconducting layer both at the conductor and the casing. The outer semiconducting layer may be connected to earth  
30 potential. To be able to cope with the problems which arise in case of direct connection of rotating electric machines to all types of high-voltage power networks, a machine according to the invention has a number of features which distinguish it from the state of the art.

35 As described above, a winding for a rotating electric

- 13 -

machine may be manufactured from a cable with one or more extruded insulated conductors with solid insulation with a semiconducting layer both at the conductor and at the casing. Some typical examples for the solid insulation are cross-linked polyethylene (XLPE) and ethylene propylene rubber. A further development of a conductor composed of strands is possible in that it is possible to insulate the strands with respect to each other in order thus to reduce the amount of eddy current losses in the conductor. One or a few strands may be left uninsulated to ensure that the semiconducting layer which surrounds the conductor is at the same potential as the conductor.

Insulation of a conductor for a rotating electric machine may be applied in some other way than by means of extrusion, for example by spraying or the like. It is important, however, that the insulation should have no defects through the whole cross section and should possess similar thermal properties. The semiconducting layers may be supplied with the insulation in connection with the insulation being applied to the conductors.

Preferably, cables with a circular cross section are used. Among other things, to obtain a better packing density, cables with a different cross section may be used. To build up a voltage in the rotating electric machine, the cable is arranged in several consecutive turns in slots in the magnetic core. The winding can be designed as a multi-layer concentric cable winding to reduce the number of end-winding-end crossings. The cable may be made with tapered insulation to utilize the magnetic core in a better way, in which case the shape of the slots may be adapted to the tapered insulation of the winding.

A significant advantage of a rotating electrical machine according to the invention is that the E field is near zero in the winding-end region outside the outer semiconductor and that with the outer casing at earth potential, the

- 14 -

electric field need not be controlled. This means that no field concentrations can be obtained, neither within sheets, in winding-end regions or in the transition between.

A winding made according to the invention is placed in the slots by threading a cable into the openings in the slots in the magnetic core. Since the cable is flexible, it can be bent and this permits a cable length to be located in several turns in a coil. The winding ends will then consist of bending zones in the cables. The cable may also be joined in such a way that its properties remain constant over the cable length. This method entails considerable simplifications compared with the state of the art. The so-called Roebel bars are not flexible but must be preformed into the desired shape. Impregnation of the coils is also an exceedingly complicated and expensive technique when manufacturing rotating electric machines today.

The invention will now be explained in more detail in the following description of a preferred embodiment, with reference to the accompanying drawings.

20 BRIEF DESCRIPTION OF THE DRAWINGS:

Figure 1 shows a cross section through a high-voltage cable; and

Figure 2 shows a side view of a high-voltage cable with a break in the third semi-conducting layer.

25 DETAILED DESCRIPTION OF EMBODIMENTS OF THE PRESENT INVENTION:

Figure 1 shows a cross-sectional view of a high-voltage cable 10 similar to that used traditionally for transmitting electric power. The high-voltage cable 10 shown may be similar to that shown in JP-A-8-195129 (145 kV) but without sheath or screen. The high-voltage cable 10 comprises an electric conductor which may consist of one or more strands



- 15 -

12 of copper (Cu), for instance, having circular cross section. These strands 12 are arranged in the middle of the high-voltage cable 10. Around the strands 12 is a first semi-conducting layer 14, and around the first semi-conducting layer 14 is a first insulating layer 16, e.g. XLPE insulation. Around the first insulating layer 16 is a second semi-conducting layer 18, and externally of the second semi-conducting layer 18 is a third semi-conducting layer 19 of lower resistivity than the second semi-conducting layer. The semi-conducting layers 14, 18, 19 are all formed from a base polymer such as ethylene vinyl acetate copolymer/nitrile rubber, butyl grafted polythene, ethylene ethyl acrylate copolymer, ethylene propene rubber or polyethylenes of high or low density, filled with carbon black.

Figure 2 shows a side view, of a portion of the high-voltage cable with a break in the third semi-conducting layer 19. As can be seen in Figure 2, the third semi-conducting layer 19 has been removed in an elongated ring around the periphery of the high-voltage cable 10 so that a break 20 is formed. The second semi-conducting layer 18 is thus exposed in the break 20. The axial length 1 of the break 20 is from 5 to 30 cm. This break in the continuity of the electric contact in the third semi-conducting layer 19 between two earthed points, ensures that limited current will flow and therefore essentially no heat losses will occur caused by induced voltages.

Our International Patent Application No. WO97/45918 describes a cable in which only the third semi-conducting layer 19 is absent and breaks are made in the second semi-conducting layer 18. In this prior invention, all interruptions in the second semi-conducting layer 18 give rise to an increase in the electric field strength at the edges of the break. The electric field strength increases sharply at the edges of the groove, which unfortunately increases the risk of electric breakdown. The embodiment of

- 16 -

the present invention shown alleviates this disadvantage because some current can still flow through the second semi-conducting layer 18 in the region below the break 20.

The high-voltage cable 10 according to Figure 1, said cable 5 10 comprising an electric conductor consisting of one or more strands 12, a first semi-conducting layer 14, a first insulating 16, a second semi-conducting 18, and a third semi-conducting layer 19 can be produced by extrusion through a suitable die. The third semi-conducting layer 19 10 will be earthed at at least two different points along the high-voltage cable. The next step is to produce a break 20 in the continuity of the electric contact in the third semi-conducting layer 19 between each earthing point. If there are N earthed points along the high-voltage cable, 15 therefore, there will be N-1 breaks 20 in the semi-conducting layer 19.

The electrical insulation of an electrical conductor according to the invention is intended to be able to handle very high voltages, e.g. up to 800 kV or higher, and the 20 consequent electric and thermal loads which may arise at these voltages. By way of example, electrical conductors according to the invention may comprise windings of power transformers having rated powers from a few hundred kVA up to more than 1000 MVA and with rated voltages from 3 - 4 kV 25 up to very high transmission voltages of from 400 - 800 kV or more. At high operating voltages, partial discharges, or PD, constitute a serious problem for known insulation systems. If cavities or pores are present in the 30 insulating material is gradually degraded eventually leading to breakdown of the insulation. The electric load on the electrical insulation in use of an electrical conductor according to the present invention is reduced by ensuring that the inner layer of semi-conductive material of 35 the insulation system is at substantially the same electric potential as conductors of the central electrically

- 17 -

conductive means which it surrounds and the semi-conductive outer layer is at a controlled, e.g. earth, potential. Thus, the electric field in the electrically insulating layer between these inner and outer layers is distributed  
5 substantially uniformly over the thickness of the intermediate layer. By having materials with similar thermal properties and with a few defects in these layers of the insulation system, the possibility of PD is reduced at given operating voltages. The electrical conductor can thus  
10 be designed to withstand very high operating voltages, typically up to 800 kV or higher.

The invention is not limited to the embodiments shown. Several variations are possible within the scope of the  
15 appended claims.

- 18 -

CLAIMS

1. An insulated conductor (10) for high-voltage windings in electric machines, characterized in that the insulated conductor comprises one or more strands (12); an inner, first semi-conductive layer (14) surrounding the strands (12); a first insulating layer (16) surrounding the inner, first semi-conductive layer (14); a second semi-conductive layer (18) surrounding the first insulating layer (16); and an outer, third semi-conductive layer (19) surrounding the second semi-conductive layer (18), which third semi-conductive layer (19) is earthed at at least two different points along the insulated conductor, the continuity of the electric contact in the third semi-conductive layer (19) being broken (20) between two consecutive earthed points.
2. An insulated conductor (10) as claimed in claim 1, characterized in that the continuity of the electric contact in the third semi-conductive layer (19) is broken by the third semi-conductive layer (19) being removed around the periphery of the insulated conductor (30) down to the second semi-conductive layer (18) so that breaks (20) are formed flanked by the third semi-conductive layer (19).
3. An insulated conductor as claimed in claim 2, wherein the axial length of each break (20) is from 5 to 30 cm.
4. A conductor according to any one of the preceding claims, characterised in that the insulating and semi-conductive layers are designed for high voltage, suitably in excess of 10 kV, in particular in excess of 36 kV, and preferably more than 72.5 kV up to very high transmission voltages, such as 400 kV to 800 kV or higher.
5. A conductor according to any one of the preceding claims, characterised in that the insulating and semi-conductive layers are designed for a power range in excess of 0.5 MVA preferably in excess of 30 MVA and up to 1000 MVA.

- 19 -

6. An electric machine comprising an insulated conductor (10) as claimed in any of claims 1 to 5.
7. A rotating electric machine as claimed in claim 6.
8. A large generator as claimed in claim 6.
- 5 9. An electric machine as claimed in claim 7 or 8, characterized in that the third semi-conductive layer (19) is electrically insulated from the stator within the stator slot and that the third semi-conductive layer (19) has at least one break and one earthing point in the overhang  
10 region for each stator slot that the cable passes through.

**THIS PAGE BLANK (USPTO)**

1 / 1

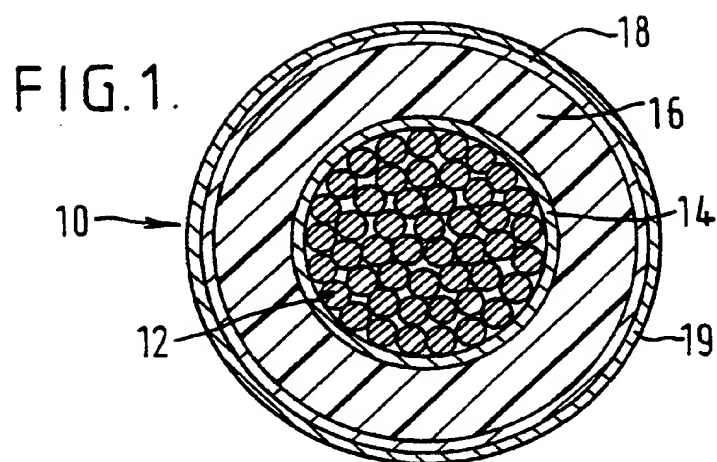
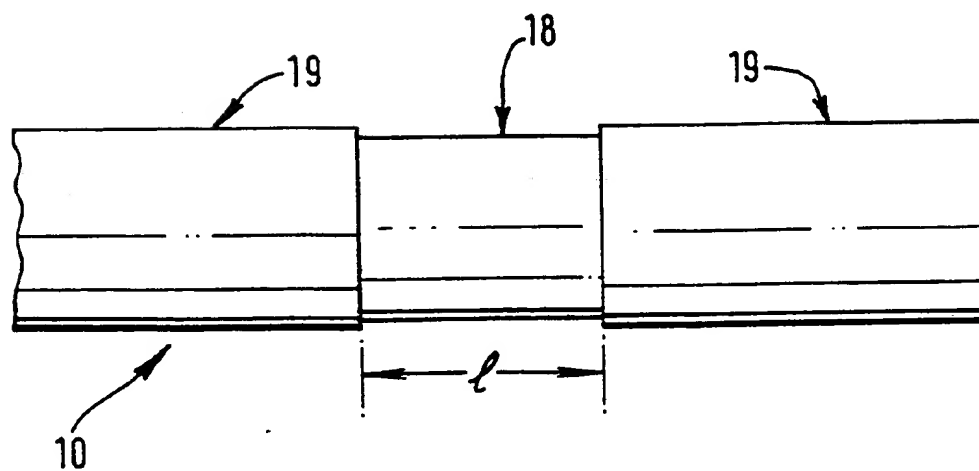


FIG. 2.



**THIS PAGE BLANK (USPTO)**



# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/EP 98/07731

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6 H02K3/40 H01B9/02

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 6 H01B H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	DE 40 22 476 A (THYSSEN) 16 January 1992 see column 1, line 31 - line 36 see column 3, line 23 - column 4, line 53; figures 1-3 -----	1 2,4,6

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

### \* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance  
"E" earlier document but published on or after the international filing date  
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)  
"O" document referring to an oral disclosure, use, exhibition or other means  
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention  
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone  
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.  
"&" document member of the same patent family

Date of the actual completion of the international search

29 April 1999

Date of mailing of the international search report

07/05/1999

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Demolder, J

**information on patent family members**

PCT/EP 98/07731

DE 4022476	A	16-01-1992	NONE
------------	---	------------	------